Development of a Ground-based 2-Micron Differential Absorption Lidar (DIAL) System to Profile Tropospheric CO_2

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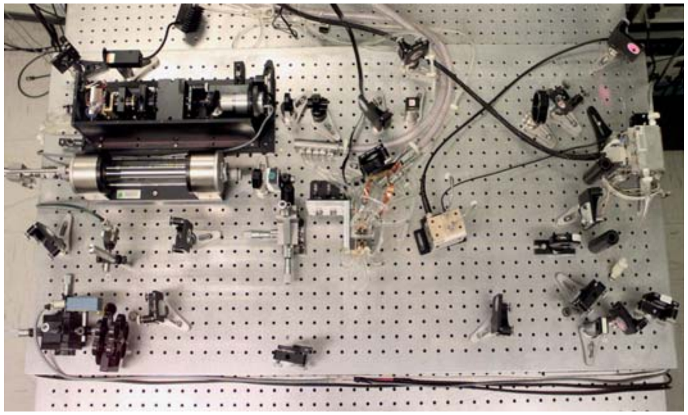
NASA ESTO Technology Conference (ESTC-06)
College Park, MD
June 25-27, 2006

Development and evaluation of a 2-micron differential absorption lidar (DIAL) for profiling CO_2

DIAL for field studies and technology development



- State-of-the-art 2-μm lasers
- Excellent CO_2 absorption lines at 2.05 microns
- High QE, low noise, high gain detectors
- Large collection area receiver

SMD Focus areas:
Carbon, Climate, and Chemistry

Objectives

- **Design, develop, and validate a high sensitivity ground-based CO_2 DIAL as an interim step towards the development of a space-based system**
- **Simultaneous CO_2 and aerosol profiling**
- **CO_2 profiles over 0-5 km altitude range with 0.5% procession**
- **Incorporate key elements of technologies needed for a future space-based system**
- **Deployable system for field studies, and as an anchor and validation tool for total column retrievals from the Orbiting Carbon Observatory (OCO)**
- **TRL objectives: Current TRL 3; TRL 4 after year 2, TRL 5 at the end of year 3**

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Schedule

Year1: Component level test, Subsystem characterization
Year 2: Lidar system test and initial evaluation
Year 3: Field deployment and full validation

There are 8 Tasks associated with this program

There are: 6 Tasks in progress at NASA Langley

- Task 1: Atmospheric modeling and data analysis software development
- Task 2: Transmitter development
- Task 3: Detector development and characterization
- Task 4: Optical design and optimization of receiver
- Task 5: Data acquisition and control
- Task 6: In situ comparisons at Langley (Year 2)

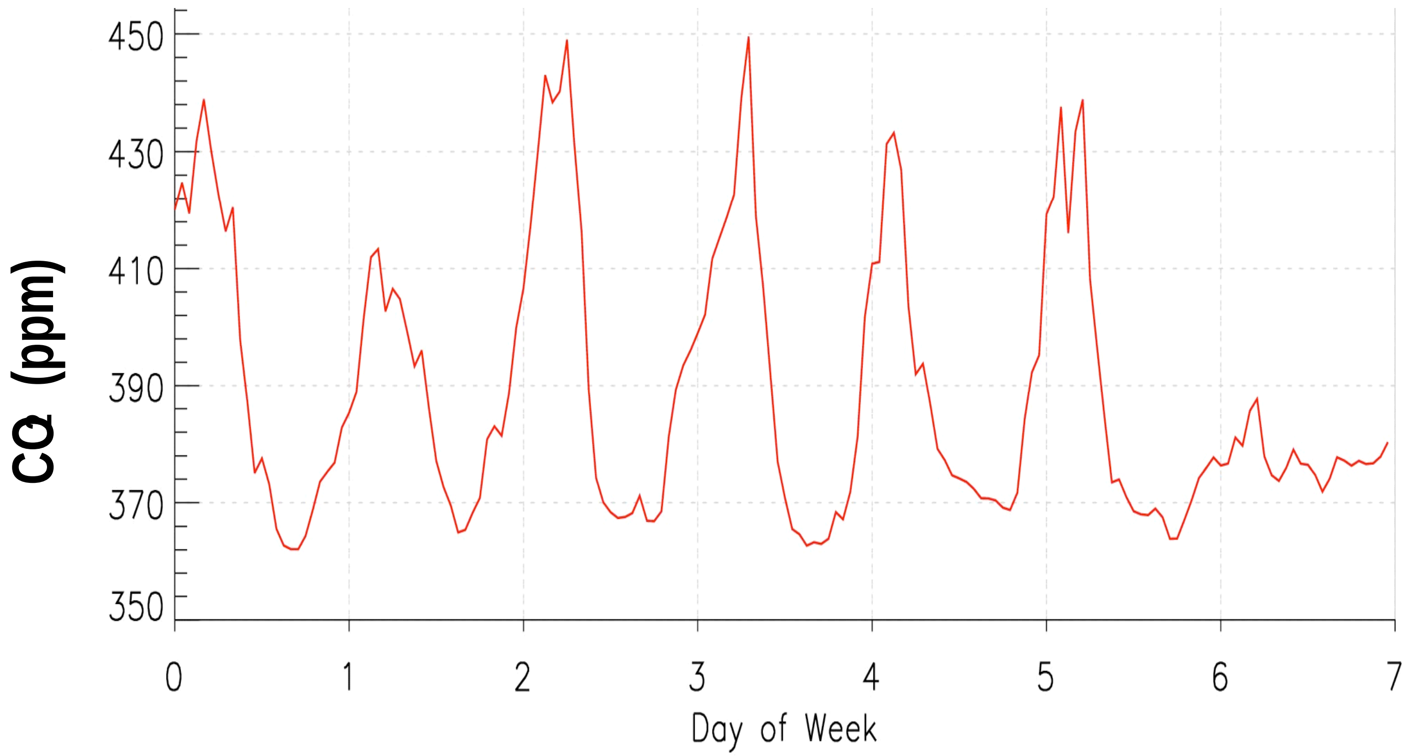
1 Task at Pennsylvania State University

Task 7: Evaluation and validation of CO_2 DIAL system

1 Task at JPL

Task 8: High resolution spectroscopy to characterize CO_2 absorption line parameters and participation in field experiment

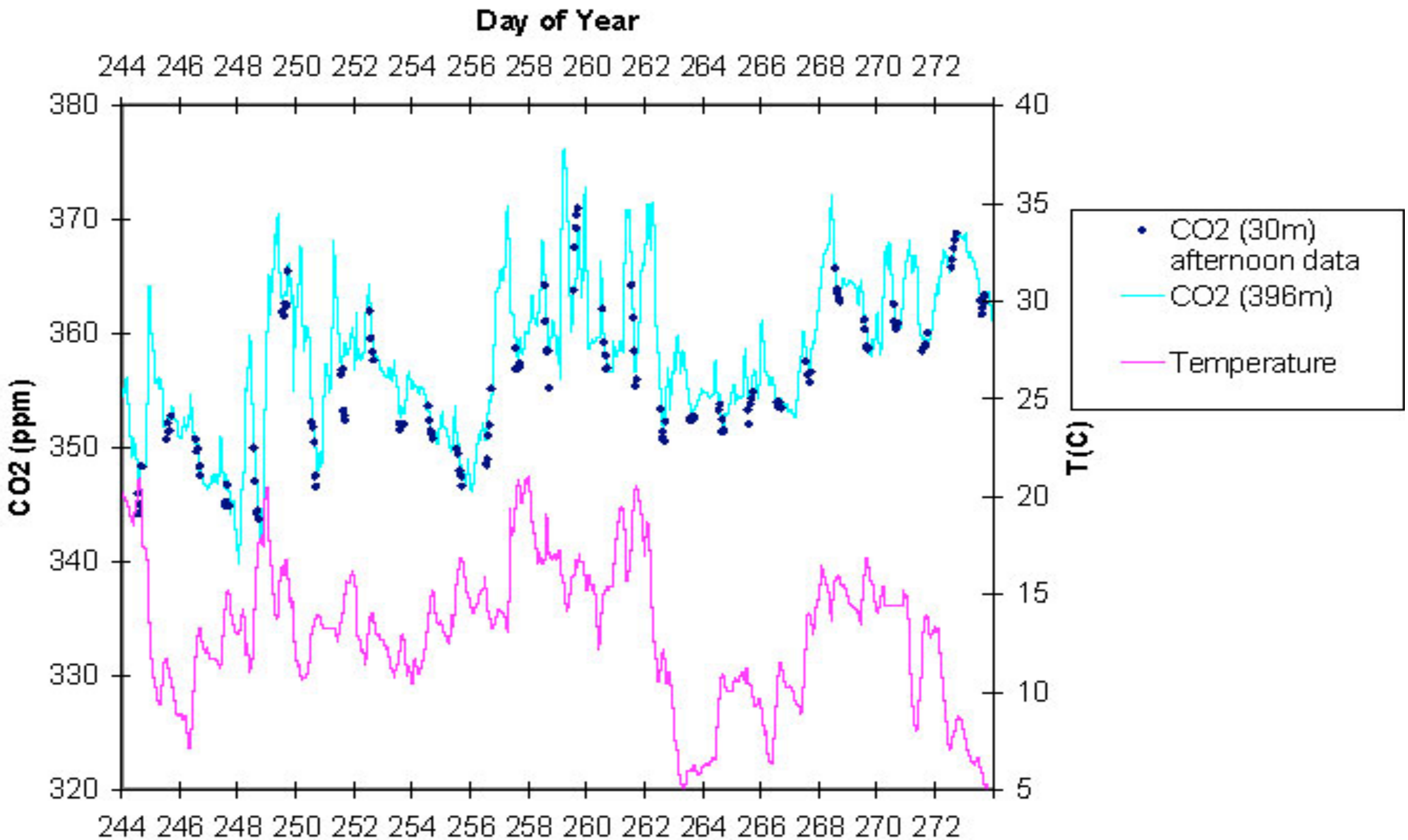
Need for Profiling of CO_2



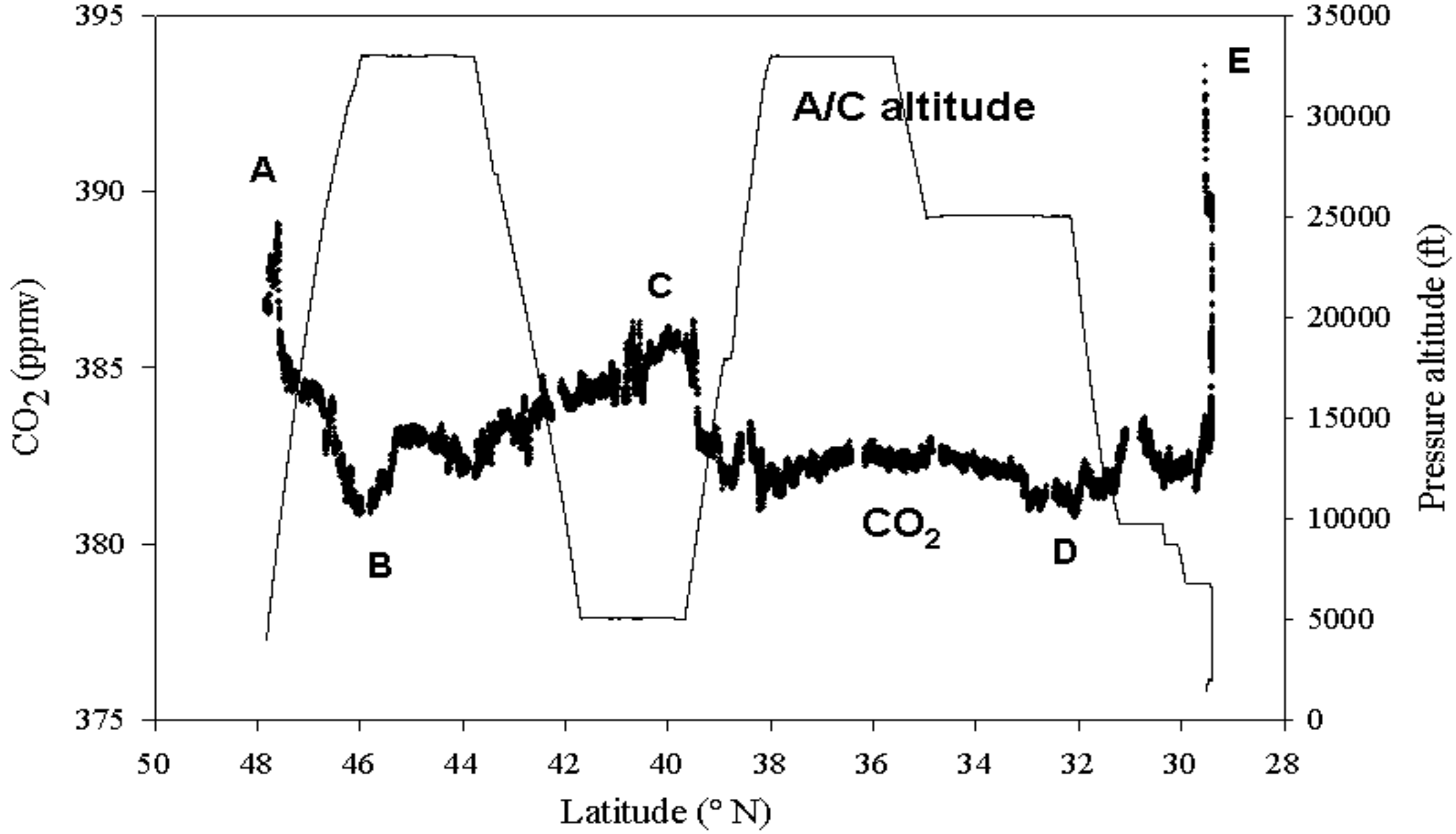
Diurnal variations of CO_2 using a NASA GSFC in situ LI-6262 sensor during the week of May 30, 2004. (Amelia Colarco, 2006)

Sources and sinks of CO_2 are located near the surface; and CO_2 is redistributed by passage of weather fronts, convection, dynamics, and transport

ABL CO_2 variations and their relation to synoptic weather

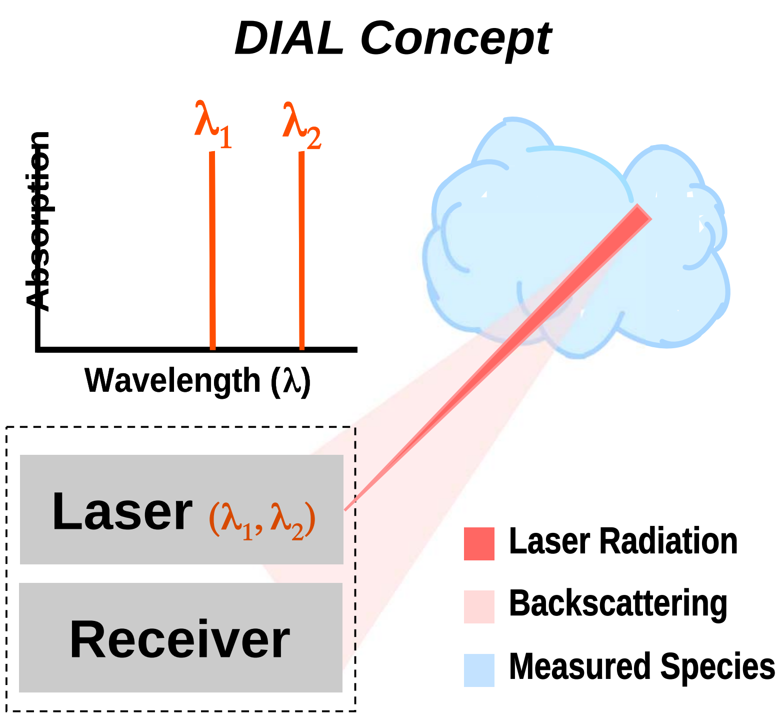


Advantage of CO_2 DIAL Profiling System



Variations in CO_2 observed along DC-8 flight track during INTEX-B using LI-6252 (Vay). Preliminary in situ data reveal A) BL to free trop transition, B) stratospheric air, C) biogenic and anthropogenic sources, D) tropical air, and E) free trop to BL transition.

Differential Absorption Lidar (DIAL) Technique and its Advantages

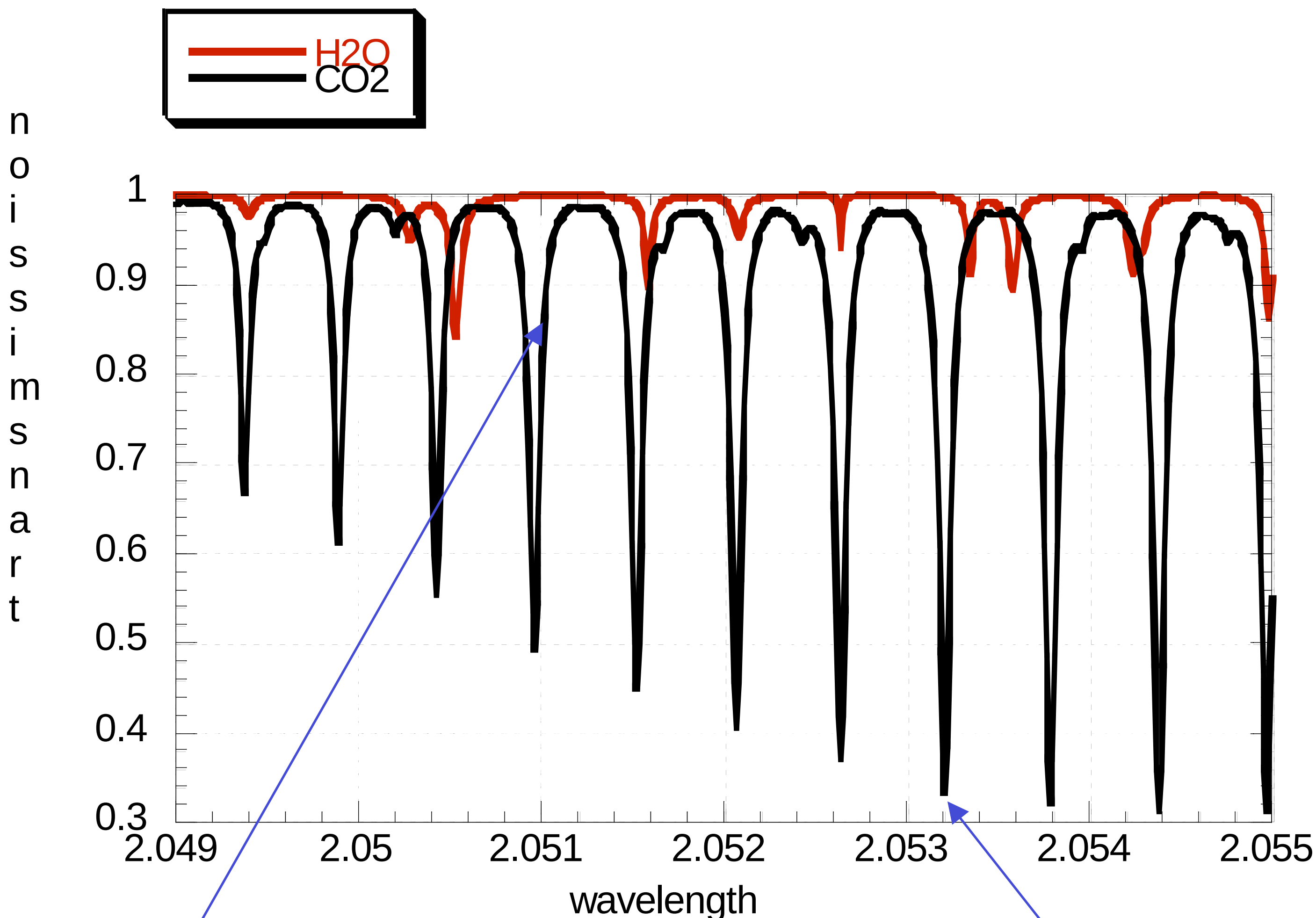


Advantages:

- **High vertical and horizontal resolution**
- **DIAL data permit direct inversion and absolute concentration measurements**
- **Simultaneous species and aerosol profiles, and cloud distributions**
- **Day and night coverage and no dependence on external radiation**

DIAL technique for Atmospheric CO_2 measurements requires suitable absorption lines; narrow-band, tunable, and line locked lasers; high efficiency and low noise detectors

Wavelength Selection



2050.967 nm: better in strength and temperature insensitivity. Moving to this line and operate on 'side-line'.

2053.204 nm: line described in proposal

Laser Developments under earlier NASA Programs Including LRRP

•Pulsed laser for range resolved profiling

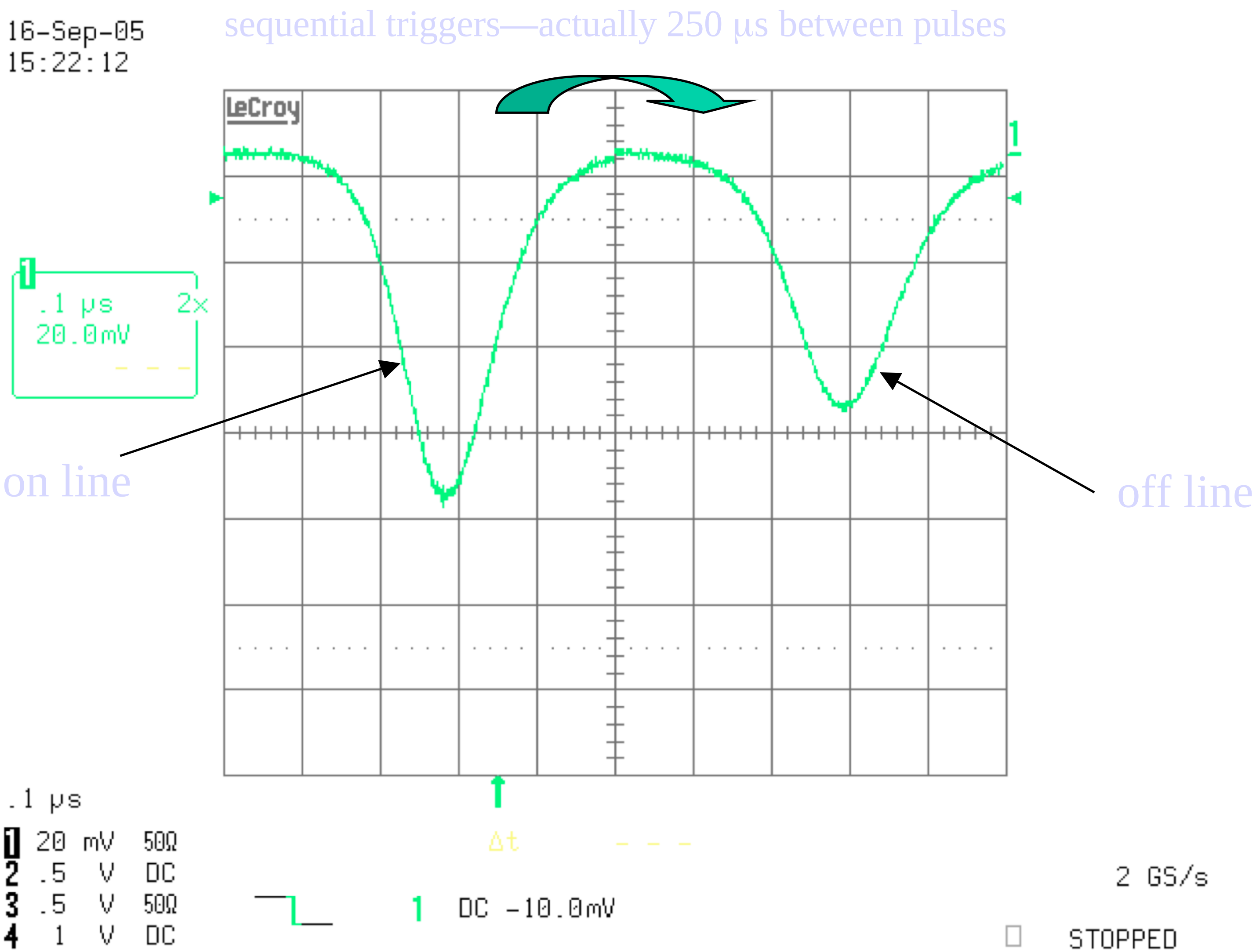
•Double pulsed operation to sample the same air mass by on- and off-laser pulses

•Wavelength stability and spectrally narrow output

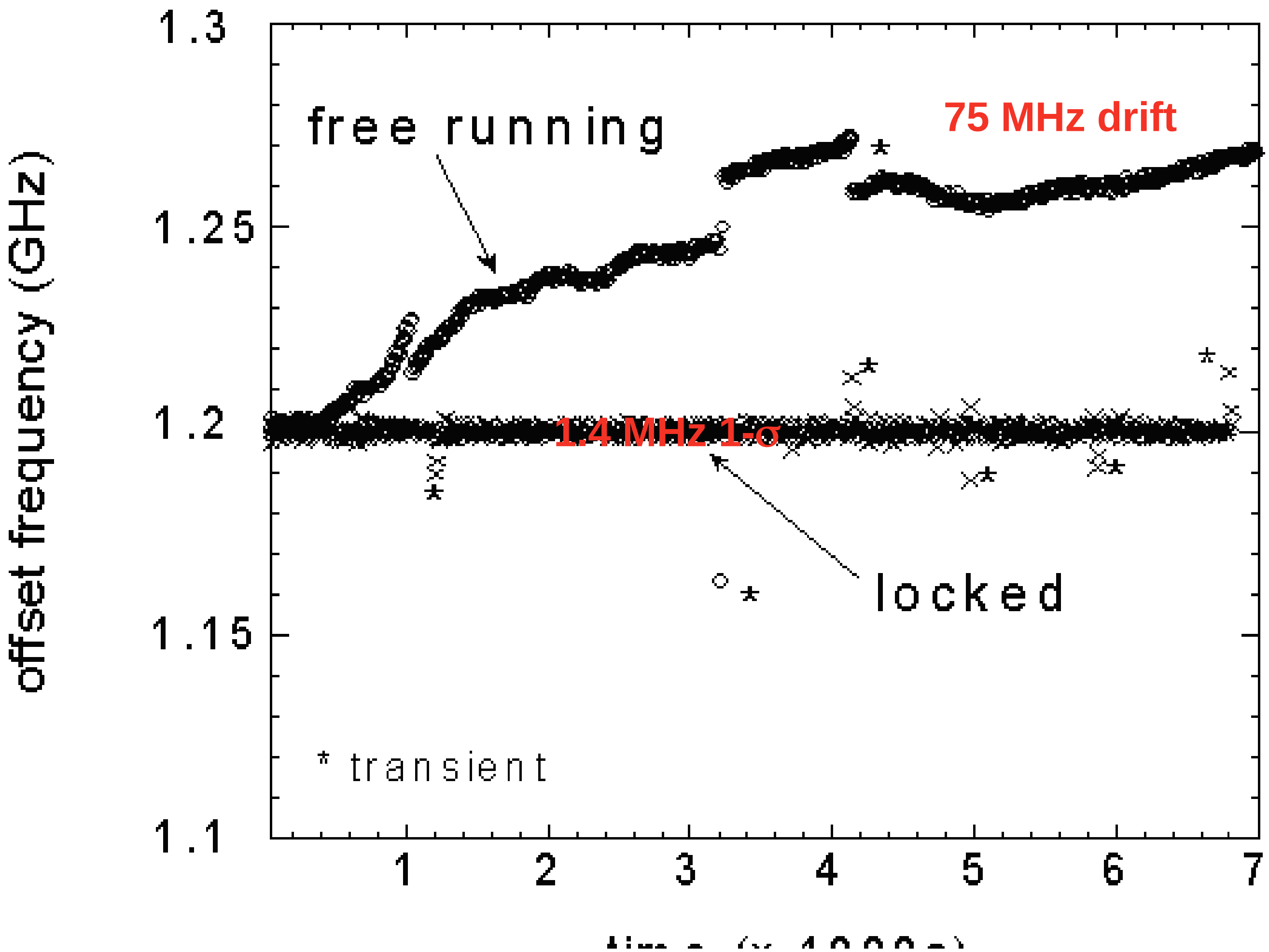
•Line-locking with respect to a selected CO_2 line

•Operation on a side of the line for optimum absorption cross-section selection

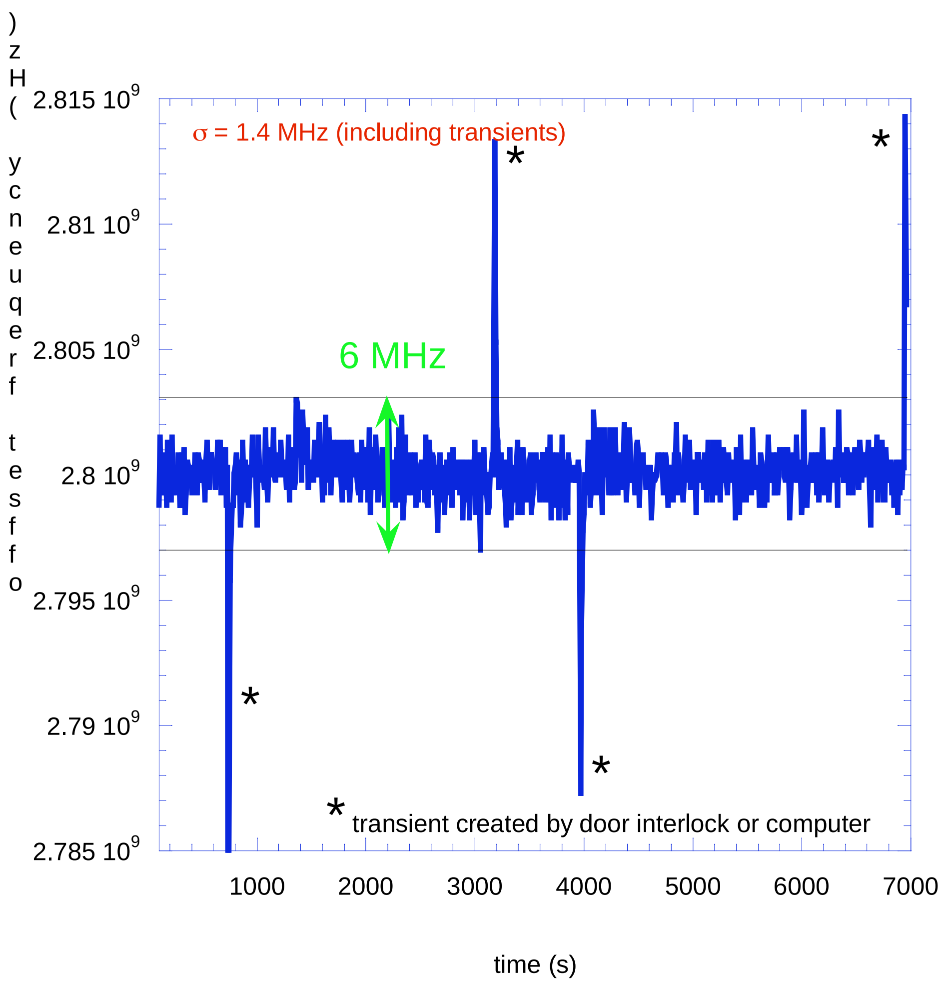
Double-Pulse Wavelength-Switched Results



Comparison of side-line tuned CW laser locked and free-running



Side Line Offset Locking Characterization



- Electronic control holds an offset from center-line locked laser.
- Offset can be electronically programmed.
- Test here assesses quality of offset lock set for 2.8 GHz (37.3 pm).

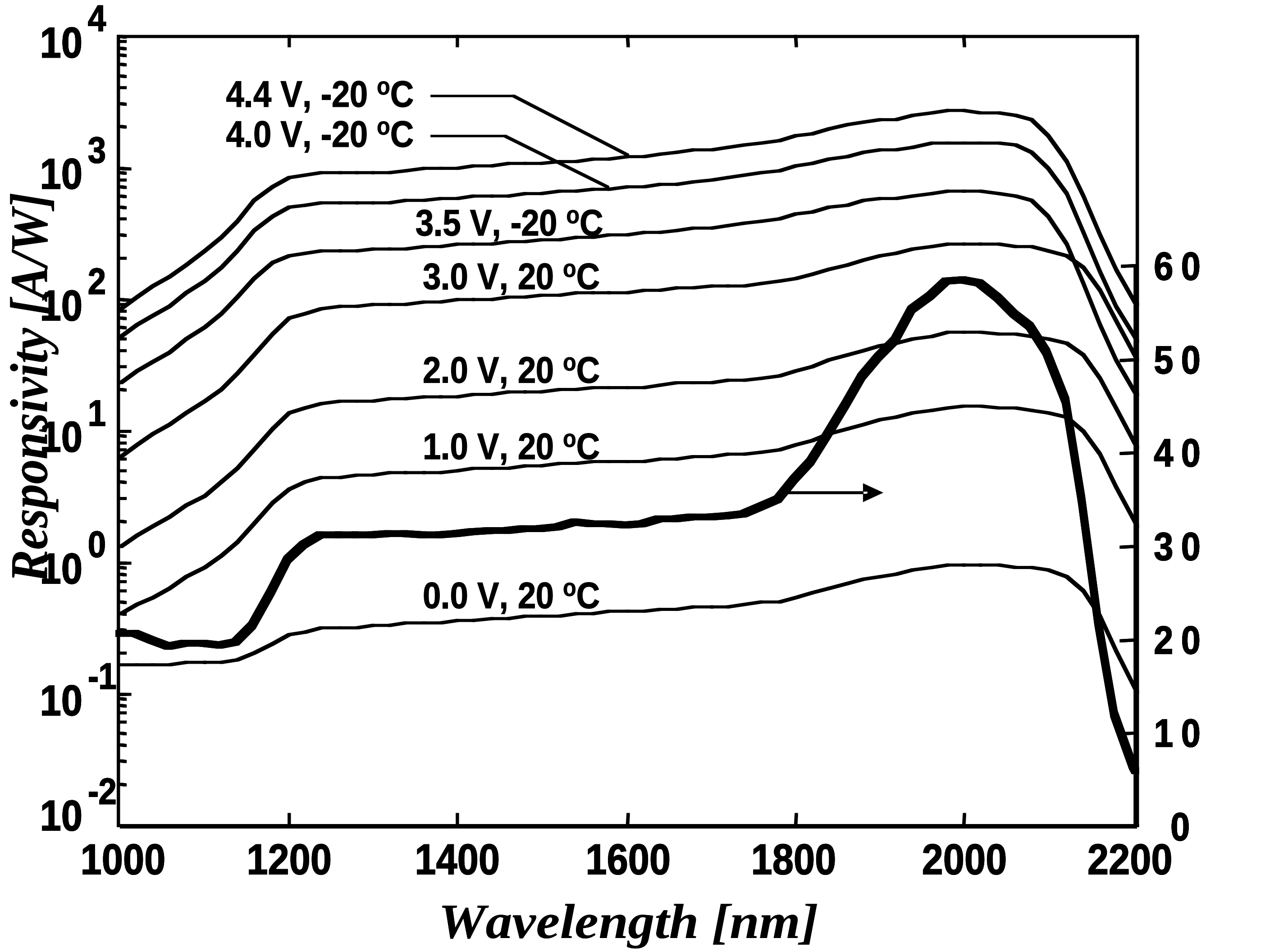
CO_2 DIAL (IIP) Goals/Requirement for detector

Advanced Detectors development needed that exceeds the performances of the commercially available detectors

- Responsivity @ 2.00-μm ≥ 50 A/W
- High operating temperature, T ~ - 20 C
- Low noise (NEP ≤ 2 to 5×10^{-14} W/√Hz) for far field
- Quantum Efficiency @ 2.00-μm ≥ 50%
- Bandwidth ≥ 10 MHz
- Collecting area diameter: 200 - 1000 μm

New AlGaAsSb/InGaAsSb phototransistors acquired and characterized at SED under LRRP—these showed high sensitivity at 2 micron wavelength.

AlGaAsSb/InGaAsSb Phototransistor With High Sensitivity at 2 μm



This detector has small (200 μ diameter) collection area

Atmospheric Tests of Phototransistors

- Atmospheric tests conducted at NCAR to test the sensitivity of small area (200 μ) phototransistors.
- High sensitivity Aerosol Scanning Lidar (REAL) system of NCAR's at Boulder, CO was used for atmospheric testing of new detectors.
- REAL operates in the 1.5 micron region and the phototransistor has reduced sensitivity in this region

Phototransistors Atmospheric Testing

Date: 5-9 June 2006

Location:

Atmospheric Technology Division

National Center for Atmospheric Research

Boulder, Colorado, 80301

Transmitter:	Receiver:
Wavelength 1543 nm	Diameter 16”
Repetition 10 Hz	Detector 200um InGaAs APD
Energy 150 mJ/pulse	Digitizer 14 Bit, 50 MS/s

Date: June 8, 2006
Time: 15:48:23 GMT
File: pic2
Elevation: 3.4
Azimuth: 310

Detector: LPE A1-b10
Bias Voltage: 3.5V
Temperature: 20oC
TIA Gain: 1000Ω
Amp. Gain: 30dB

Raw File: REAL.20060608_153255.bscan
Comments: Aligning the phototransistor to the hard Target (mountain top at about 14 km). Some feature appears at about 3 km, which dominated with the TIA overshoot.

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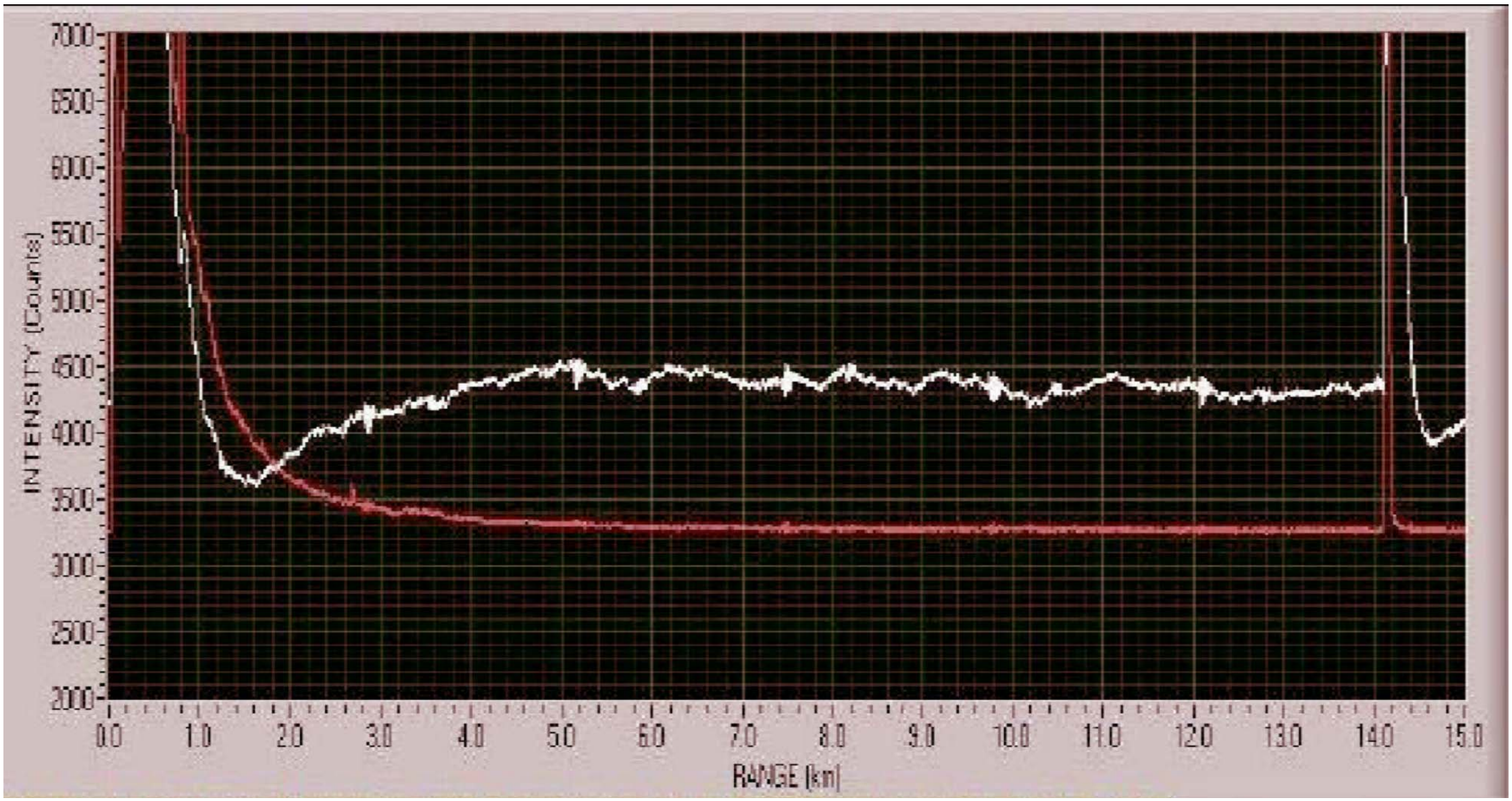
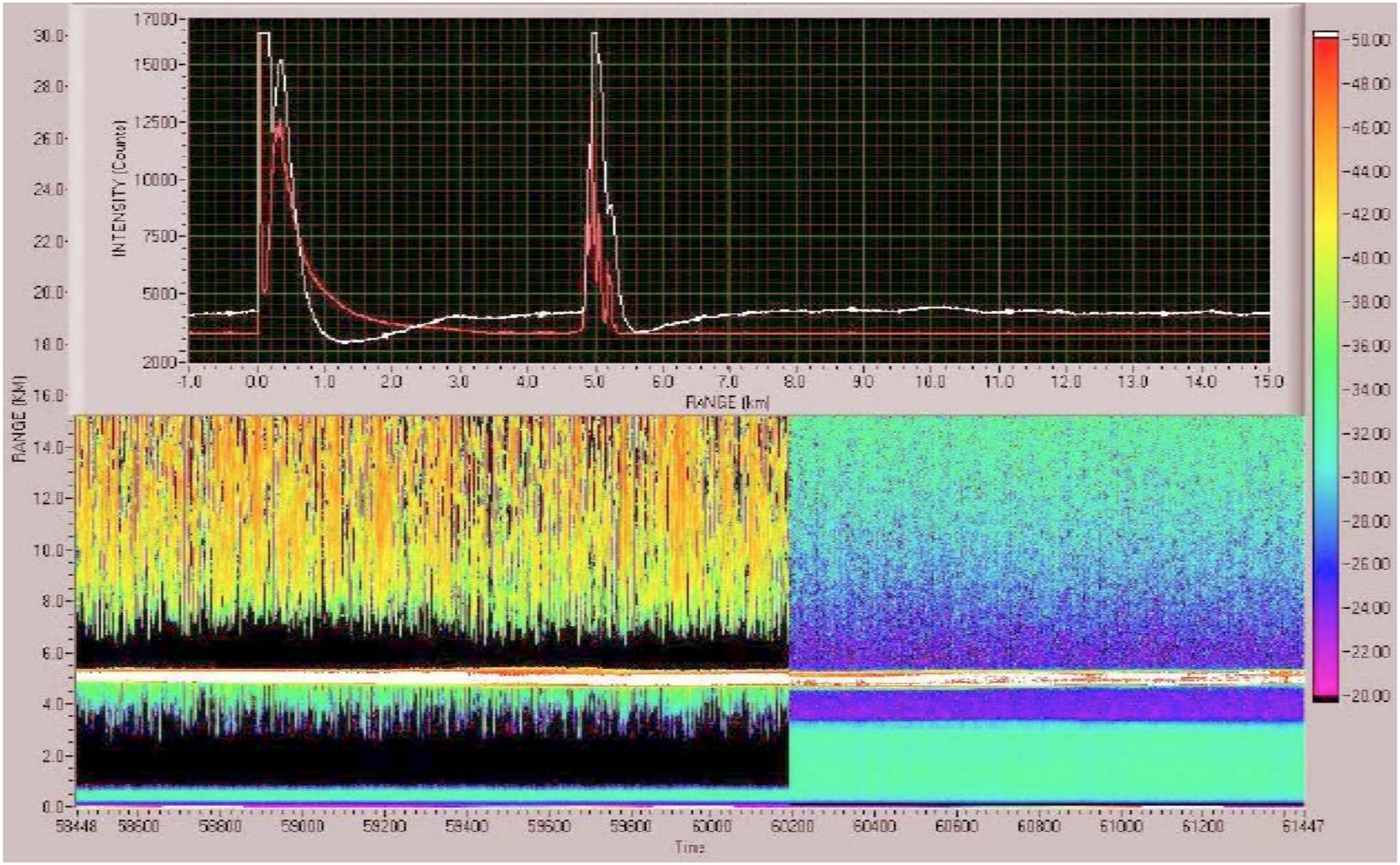


Date: June 8, 2006
Time: 16:22:09 GMT
File: pic6
Elevation: 90
Azimuth: 310

Detector: LPE A1-b10 Raw
Bias Voltage: 3.5V
Temperature: 20oC
TIA Gain: 1000Ω
Amp. Gain: 30dB

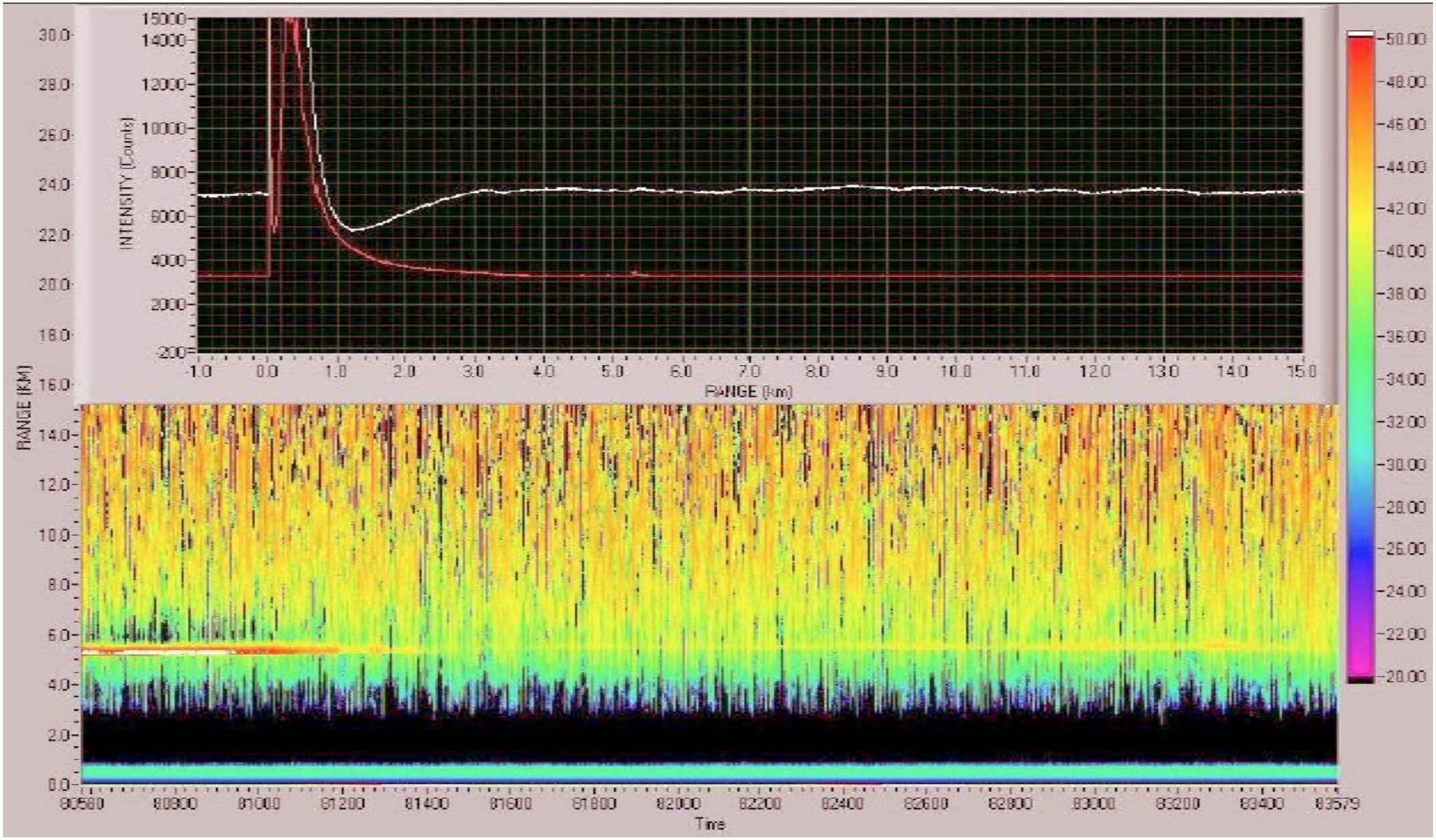
File: REAL.20060608_153255.bscan
Comments: Looking at thin cirrus cloud at 5 km. The cloud gets thinner. Even the boundary layer, at about 3 km, can be seen with the phototransistor.



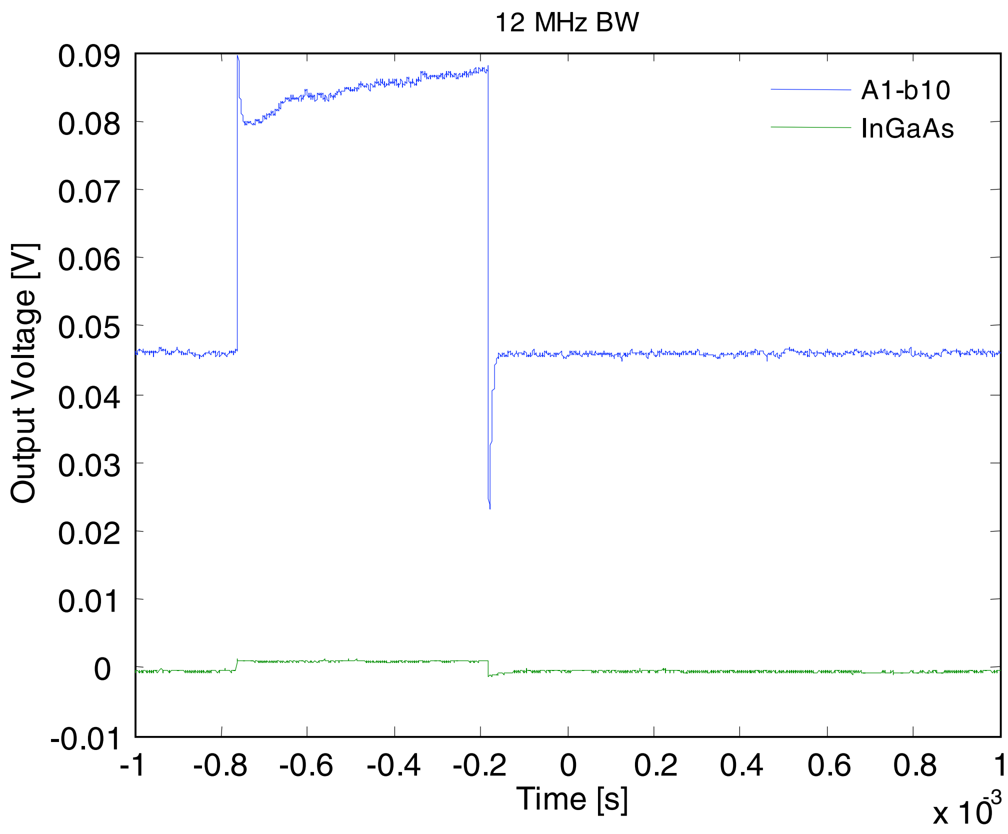
Date: June 8, 2006
Time: 16:40:44 GMT
File: pic10
Elevation: 90
Azimuth: 310

Detector: LPE A1-b10
Bias Voltage: 3.5V
Temperature: 10oC
TIA Gain: 1000Ω
Amp. Gain: 30dB

Raw File: REAL.20060608_162626.bscan
Comments: Cooling the phototransistor to 10°C
Although the feature becomes very weak (20% above bkgd.)
But still can be detected easily with the
phototransistor (SNR is about 1)



TIA tests with two detectors using pulsed 1.5 m laser

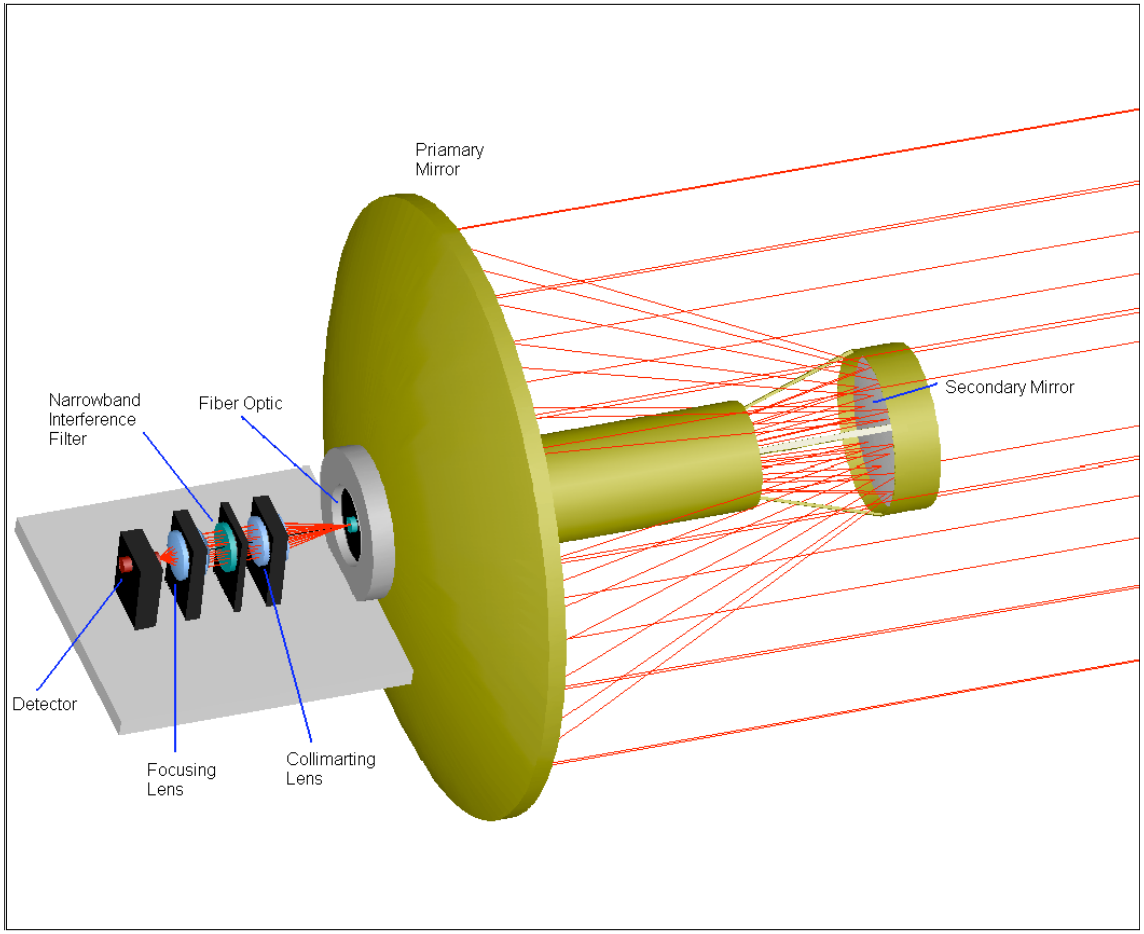


TIA induced over-shoot seen in both detectors

CO_2 DIAL Optical Receiver Design

Objectives: Large collection area, focus light onto a small detector, and full beam overlap within a short (0. 5 km) distance.

3-D View of the Receiver:



Conclusions

- During the first year, component level characterization and testing is in progress.
- System will operate at a temperature insensitive CO_2 line (2050.967 nm) with optimum absorption cross-section.
- An order of magnitude improvement laser line locking needed for high precision measurements, side-line operation, and simultaneously double pulsing and line locking demonstrated.
- Detector testing of phototransistor has demonstrated sensitivity to aerosol features over long distances in the atmosphere and optical systems that collect light onto small area detectors work well.
- TIA designs are being improved.
- Receiver optical designs are being optimized and data acquisition systems developed